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TECHNICAL DOCUMENT 3036
August 1998

In-Situ Laser Doping of Silicon Carbide

Presentation at the March 1998 Meeting of the American Physical Society

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ADMINISTRATIVE INFORMATION

The work detailed in this document was performed for the Office of Naval Research (ONR 334) by the Advanced Technology Branch, Code D853, Space and Naval Warfare (SPAWAR) Systems Center, San Diego. Funding for this project was provided under program element 0603508N.

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INTRODUCTION

This document is a compilation of posters presented at the March 1998 meeting of the American Physical Society in Los Angeles, CA. It summarizes the inherent difficulties in fabricating silicon carbide microelectronic devices, the novel laser set-up used to form electrical junctions in silicon carbide, detailed analyses of the laser-processed materials, and applications for this technique. This is the first reported demonstration of incorporation and activation of dopants into silicon carbide using excimer laser recrystallization in the presence of a doping ambient.

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Space and Naval Warfare Systems Center
Advanced Technology Branch (Code D853)
San Diego, CA

American Physical Society
16-20 March 1998, Los Angeles, CA
Paper O38.86

Abstract

In-situ incorporation of boron into silicon carbide is demonstrated using excimer laser recrystallization in a boron trifluoride ambient. Rutherford backscattering spectroscopy and x-ray analyses demonstrate there is no crystalline damage during recrystallization at laser fluences below ~1.4 J/cm^2. Point-contact current-voltage measurements confirm dopant activation, and the formation of shallow (~60 nm) pn-junctions in silicon carbide. This technique may be applied to the fabrication of shallow junctions and low resistance contacts in silicon carbide power devices without ion implantation and furnace annealing.

Background

Silicon carbide (SiC) is a semiconductor of wide interest due to its applications in high temperature, high power and photonic devices and circuits.[1-3] However, difficulties in fabrication, as compared to silicon, have prevented the full realization of its capabilities in these areas. The high melting point[4] and limited diffusion of impurities[5] have greatly limited the use of ion implantation and furnace annealing commonly employed in the silicon microelectronics industry as a means of incorporating and activating dopants.

Limited success with ion-implanting n-type dopants in SiC, such as arsenic, has been obtained but require furnace anneals > 1300°C for activation.[6,7] However, ion implantation and furnace annealing of p-type dopants has demonstrated only about 5% activation,[8,9] insufficient for practical device fabrication.

Attempts at using lasers to activate ion implanted dopants have demonstrated various degrees of success,[10-14] however all require ion implantation of dopants prior to annealing in order to form electrical junctions.

Experimental

Single crystal 4H-SiC and 6H-SiC wafers, oriented 3.5° off-axis from the (0001) plane, were obtained uniformly pre-doped n-type with nitrogen or aluminum at a level of about 1.5×10^{18} cm^{-3}. The as-received 30 mm or 35 mm diameter wafers[15] were cut into smaller samples to accommodate subsequent electrical and crystalline characterization. Laser processing was performed on the polished, silicon-terminated, face. Laser recrystallization experiments were conducted using a Questek model 2860 KrF excimer laser operating at 248 nm. Pulse repetition rates of 1 or 2 Hz were used with pulse energies up to 700 mJ. The laser intensity profile was homogenized, shaped and directed normal to the sample surface. See the experimental set-up in FIG. 1.

In-situ reflectivity measurements were used to confirm the onset and monitor the melt duration of the 4H-SiC samples. A melt threshold of ~0.8 J/cm^2 was determined by the observation of increased reflectivity as measured by a 790 nm AlGaAs laser diode impinging on the excimer laser illuminated region. Melt duration increased linearly from 25 ns to 55 ns as the fluence changed from 0.9 J/cm^2 to 1.8 J/cm^2. Similar results were obtained for 6H-SiC. See the experimental set-up and the corresponding oscilloscope traces in FIG. 2, and the variation in melt duration vs. laser fluence in FIG. 3.

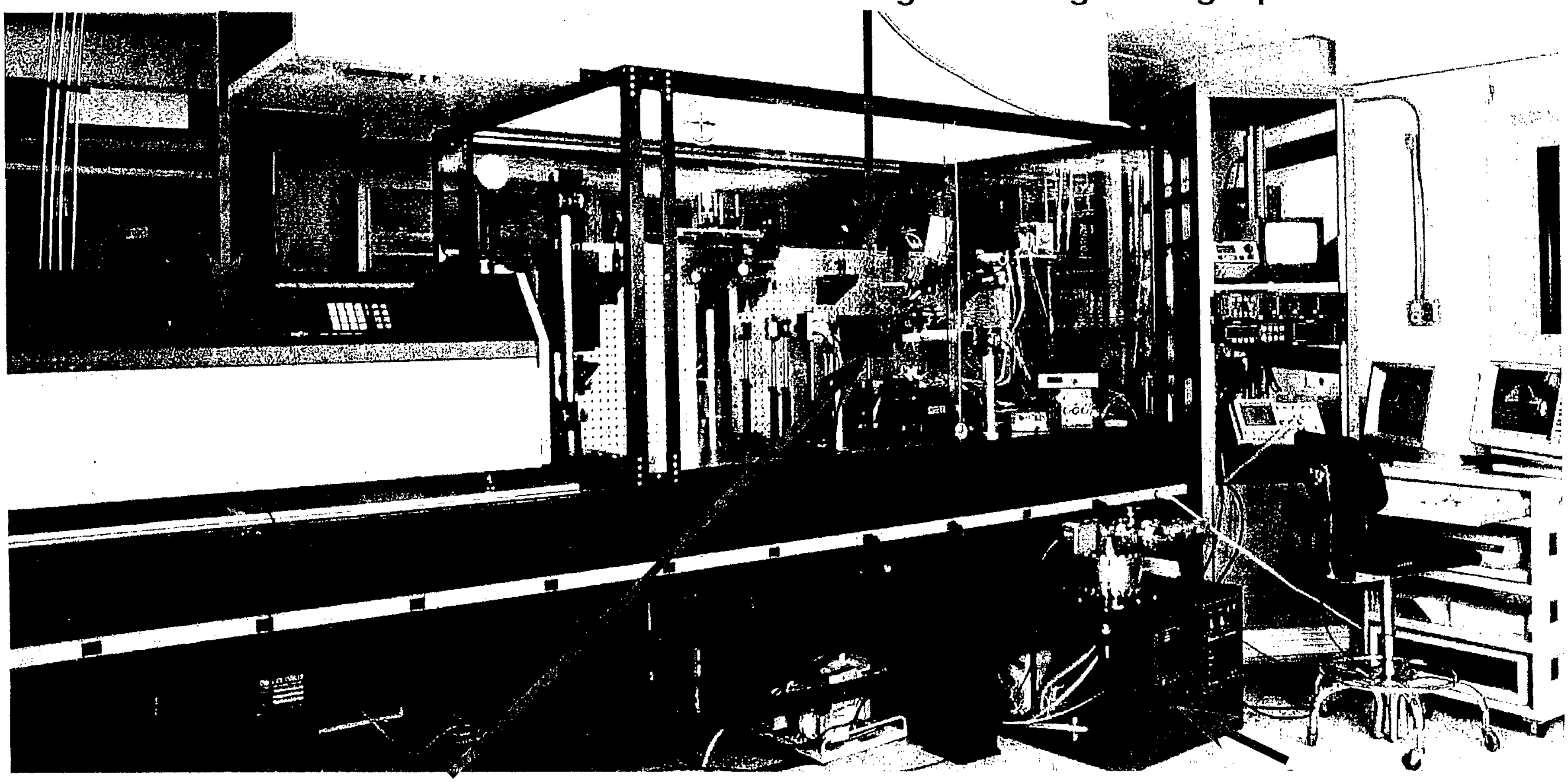


FIG. 1 Primary components of the excimer laser processing system.

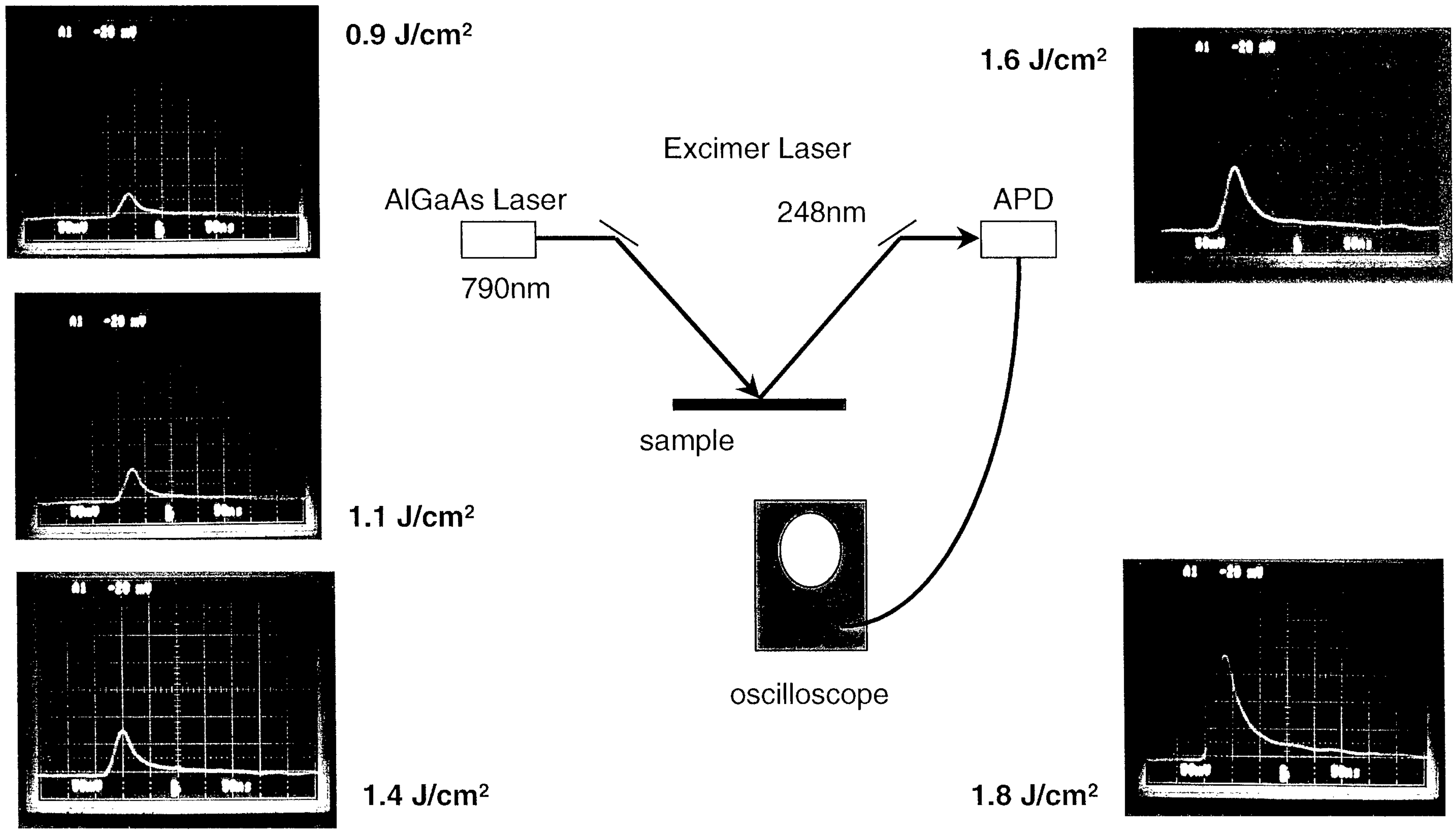
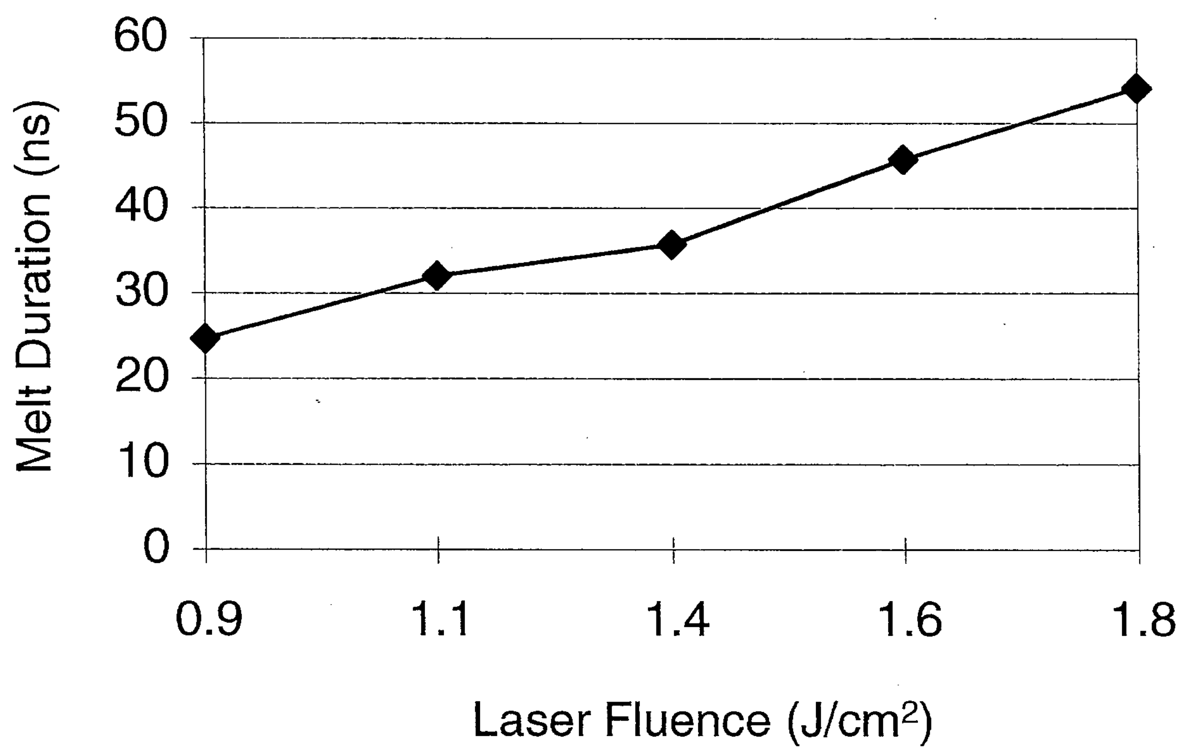


FIG. 2 Schematic of in-situ reflectivity monitor and resulting oscilloscope traces.



$\Phi_{MELT} \approx 0.8 \ J/cm^2$

FIG. 3 Melt duration versus laser fluence.

X-Ray Analysis

4H-SiC samples were illuminated with fluences ranging from 1.2 J/cm^2 to 2.0 J/cm^2 in a processing chamber with a 10 psi helium atmosphere to avoid reaction of the molten SiC with air. A Rigaku D/MAX-RBX diffractometer was used to make theta-2-theta and rocking curve scans of each laser illuminated sample and an unprocessed reference. The K-alpha x-ray lines of a Cu target were diffracted by the sample and directed to a scintillation counter detector by a diffracted beam monochrometer. A 0.25 mm thick molybdenum mask with 2.1 mm aperture, and beveled edges to minimize shadowing, was used to ensure that the x-ray beam was diffracted only from the area of interest.

The two principle SiC peaks at 2-theta values of about 35.5° and 75.3° are easily detected, corresponding to diffractions from the (004) and (008) crystal planes.

Laser recrystallized samples showed no evidence of changes in the SiC polytype, unlike that of implanted and furnace annealed samples of Pezoldt et al.[16] A measurement of the disruption of the SiC (001) crystal planes, which produce the (004) and (008) peaks, was obtained by observing changes in the half-width of the rocking curves.

X-Ray Analysis (continued)

The half-width for 1 laser pulse at 1.2 J/cm^2 normalized to an unilluminated region is shown in FIG. 4. No significant broadening is observed, indicating resolidification without introduction of new defects into the sample.

FIG. 5 compares the x-ray rocking curve linewidth for unilluminated SiC with laser illuminated samples at higher fluences. FIG. 6 is a plot summarizing the effects on the normalized rocking curve half-width with changes in laser fluence. Increased laser fluence, above ~1.4 J/cm^2, shows an increase in half-width indicative of the formation of defects. However, between the melt threshold of ~0.8 J/cm^2 and ~1.4 J/cm^2, there is no evidence of crystalline damage.

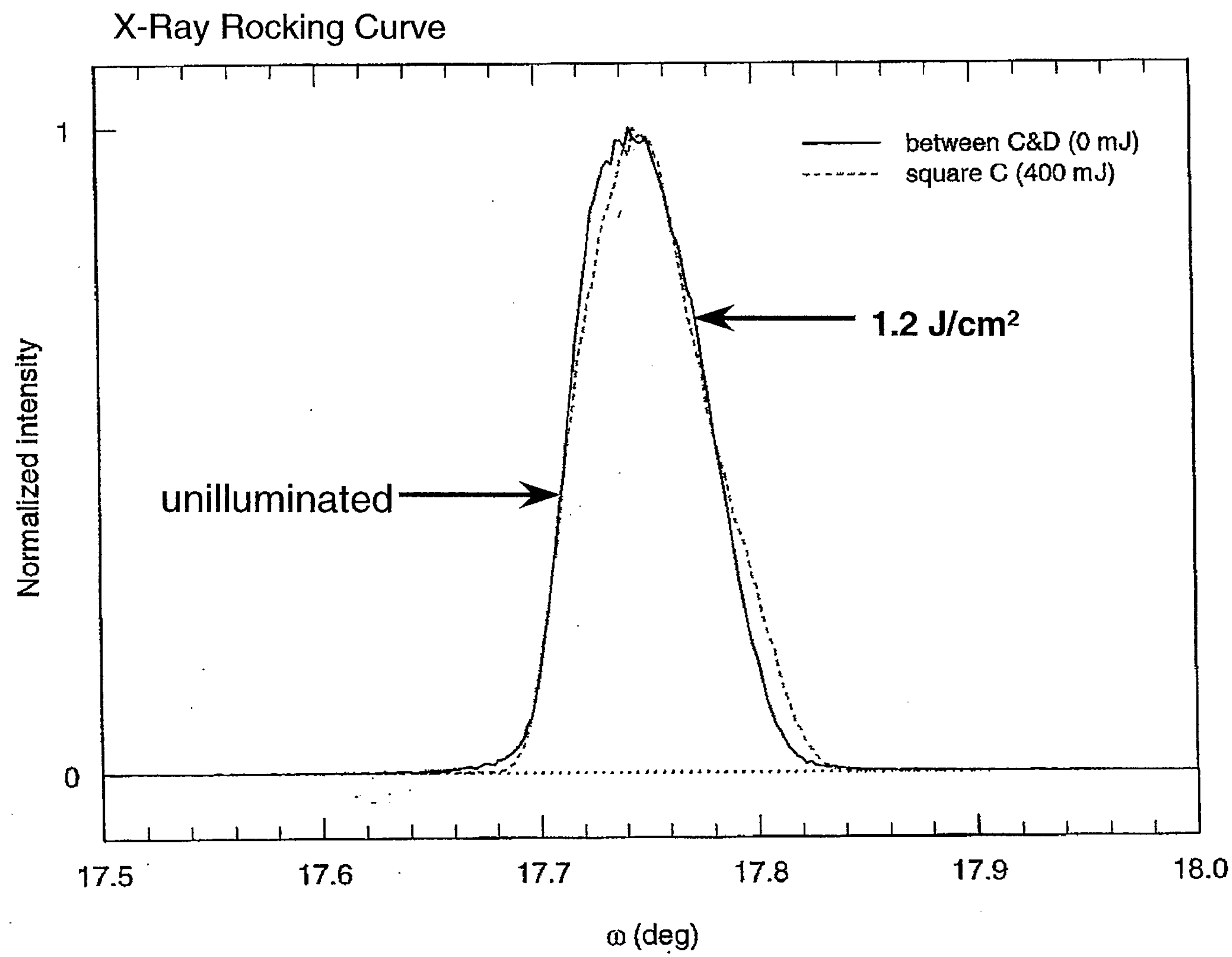


FIG. 4 X-ray rocking curve linewidth comparison of unilluminated and laser illuminated SiC.

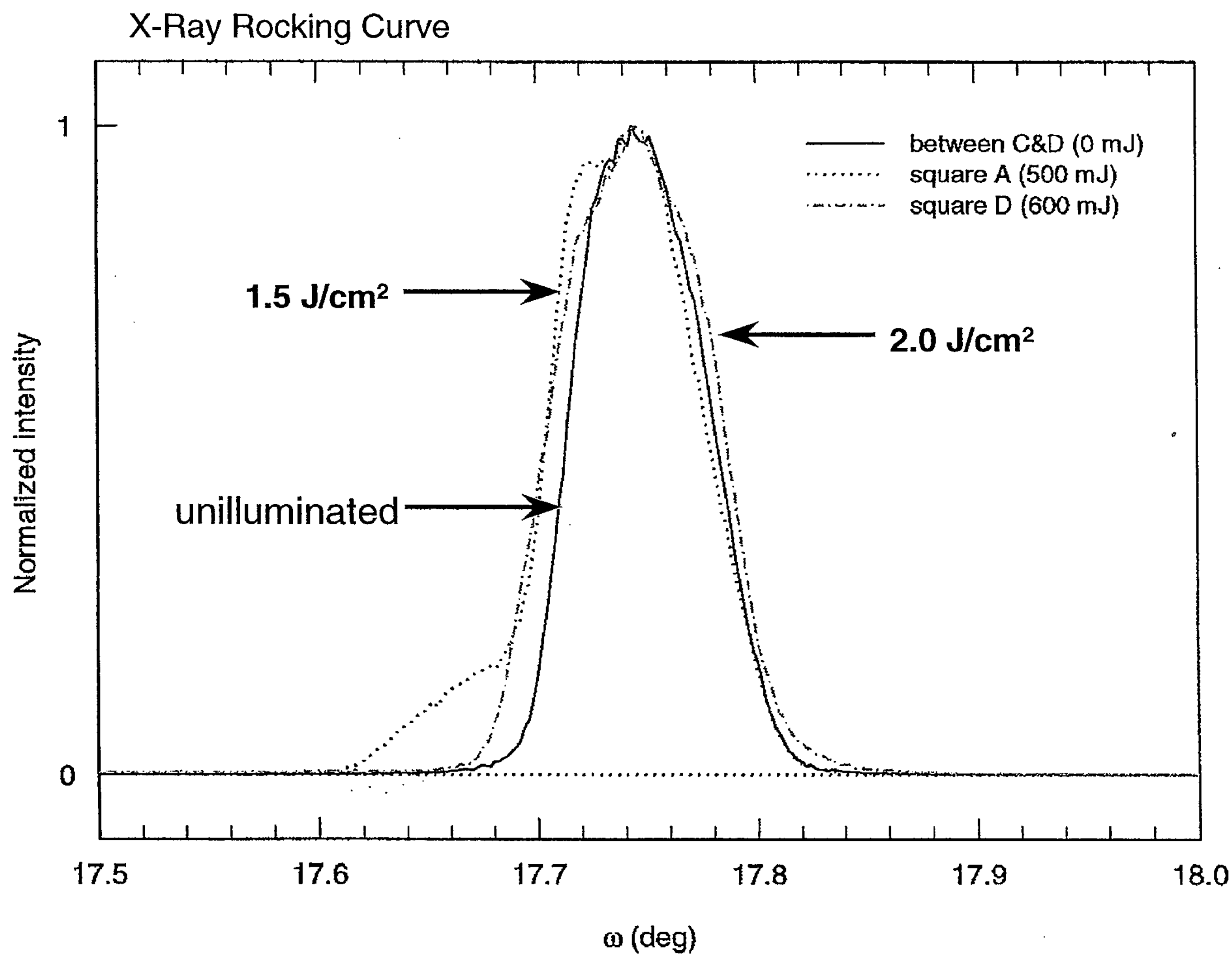


FIG. 5 X-ray rocking curve linewidth comparison of unilluminated and laser illuminated SiC.

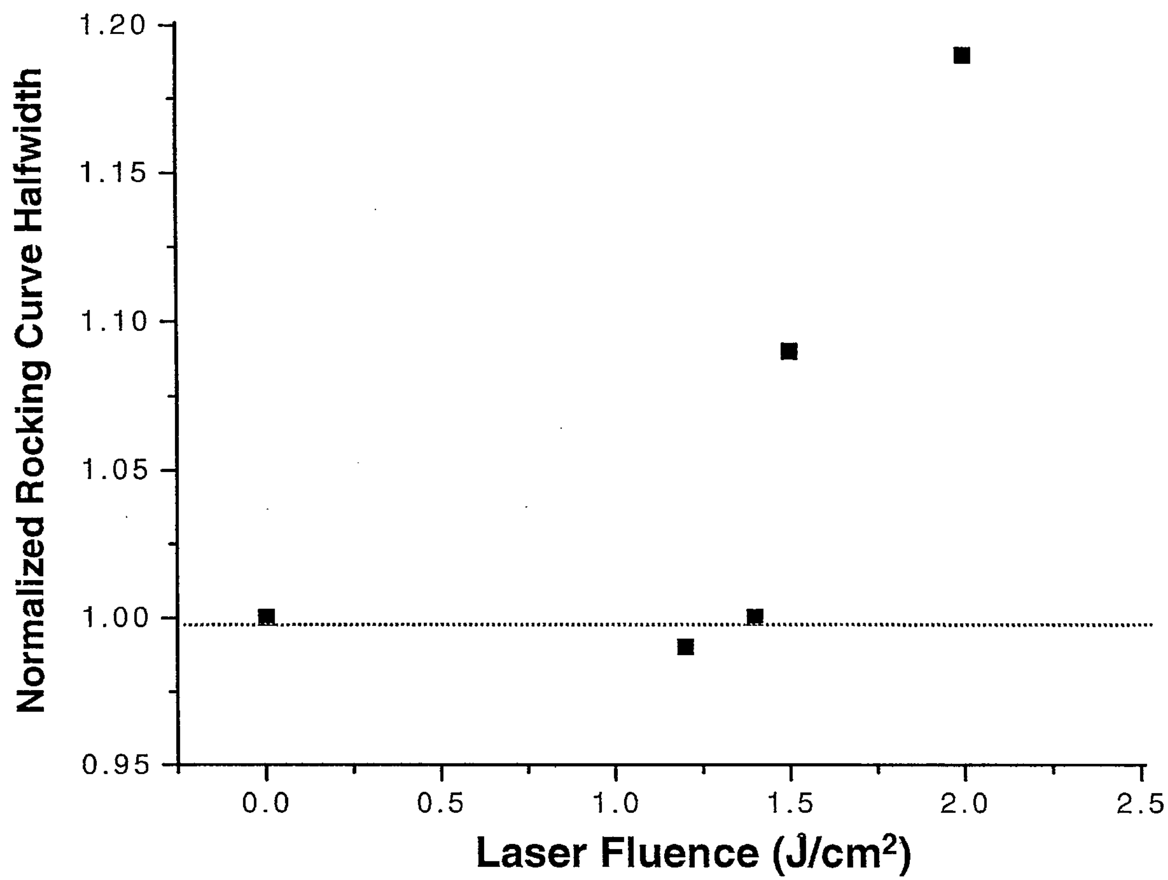


FIG. 6 Normalized rocking curve half-width versus laser fluence.

RBS Analysis

SiC samples were illuminated in a controlled ambient with fluences ranging from 1.2 J/cm^2 to 2.4 J/cm^2. Rutherford Backscattering Spectrometry (RBS) ion channeling studies using 2.275 MeV $^4He^{+2}$ ion beam (I_b = 50 microCoulombs) was used to quantify the degree of crystal damage and confirm the x-ray results.[17] Channeled and rotating random RBS spectra were acquired at a detector angle of 160° and a glancing angle detector of 105° from the forward trajectory of the incident He ion beam for each sample. The 105° glancing angle detector is sensitive to surface layers and was used to obtain precise damage depths.

FIG. 7 shows the RBS yield of the 105° detector vs. channel number (depth) for unilluminated 4H-SiC, and for samples with one pulse at 1.2, 1.4, 2.0 and 2.4 J/cm^2. The corresponding rotating random spectra is shown with a dashed line. The percentage of crystalline damage is obtained by comparing the de-channeled yield with that of the random spectra, and accounting for surface scattering. FIG. 8 shows the percent damage versus laser fluence which is consistent with the x-ray analysis. Laser fluences above ~1.4 J/cm^2 exhibit substantial damage (nearly 40%) while higher fluences (> 2.0 J/cm^2) completely amorphize the surface layer of the SiC.

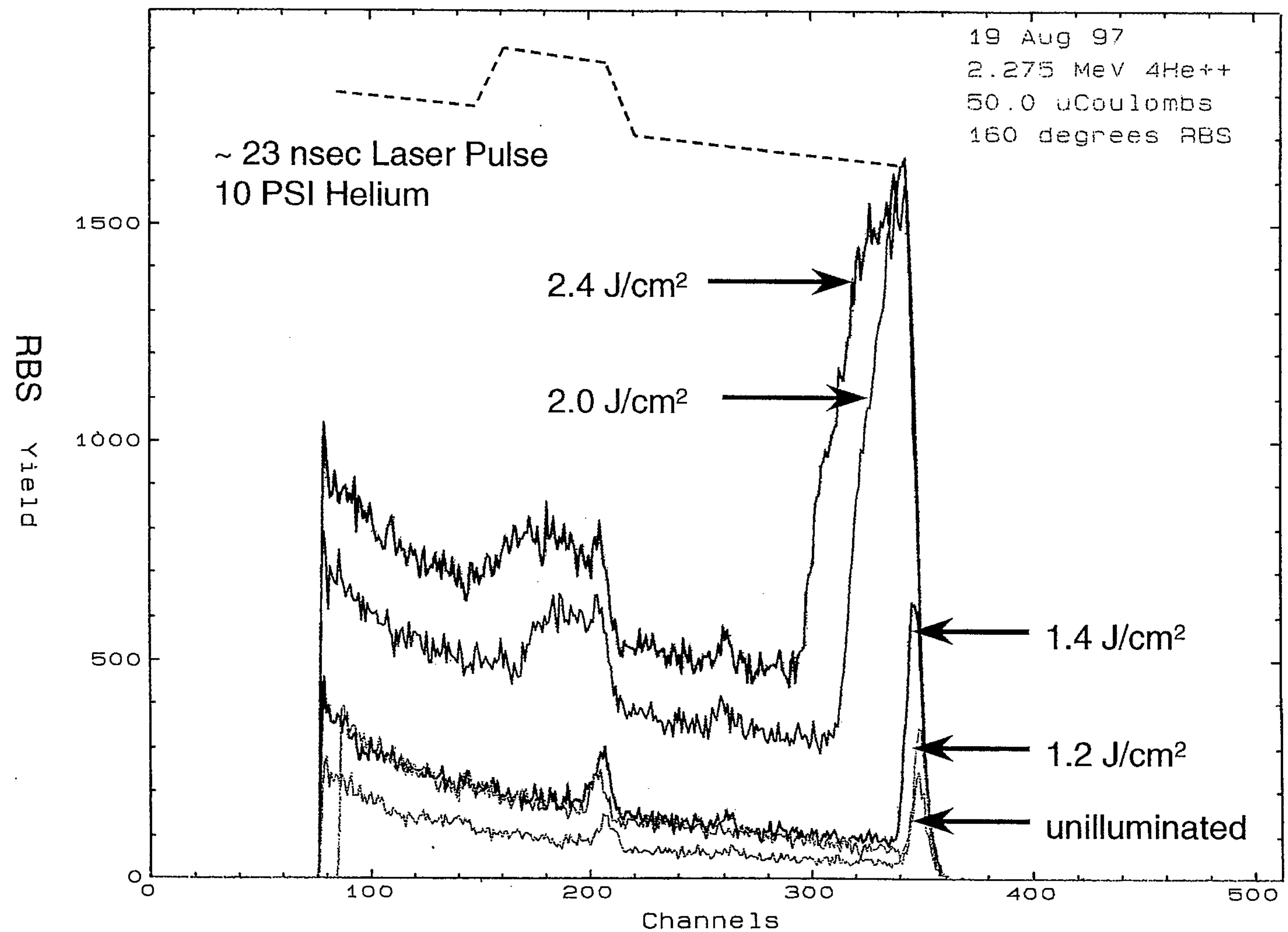


FIG. 7 RBS yield versus depth.

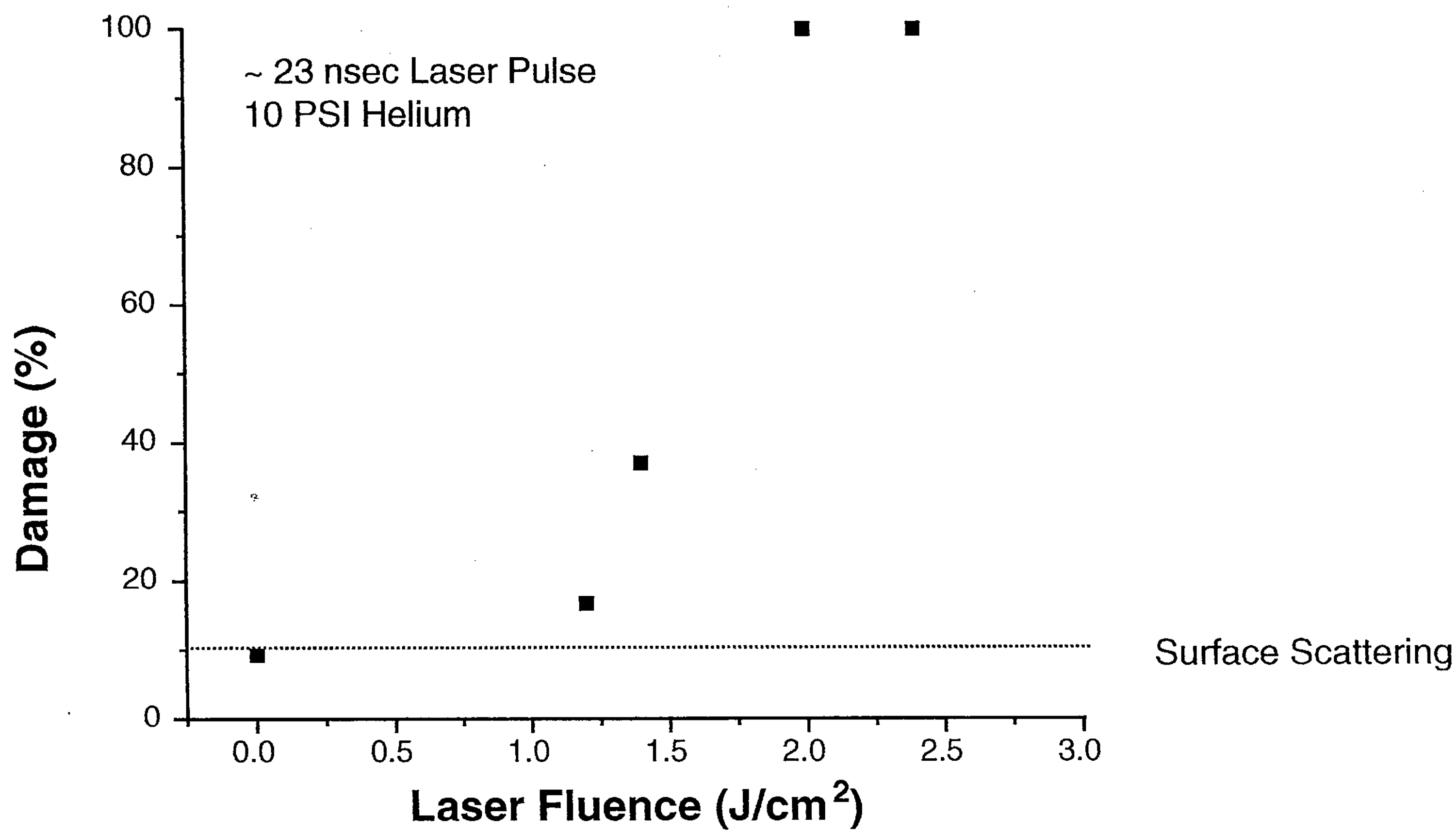


FIG. 8 Percent damage versus laser fluence.

Laser Doping of SiC

6H-SiC samples were placed in a processing chamber with a 10 psi ^{11}B-enriched boron trifluoride atmosphere. The samples were subsequently illuminated with a single pulse with fluences ranging from 1.1 J/cm^2 to 1.3 J/cm^2 (insufficient to cause damage). Point-contact current -voltage (PCIV) measurements were performed in the laser illuminated region to determine the concentration of electrically active carriers.[18] FIG. 9 shows the PCIV voltage versus depth (dashed line) and carrier concentration (solid line) versus depth for one pulse at 1.1 J/cm^2. Boron incorporation and activation is observed with a carrier concentration of 3.4×10^{18} cm^{-3} with a junction depth of 60 nm.

^{11}B-enriched BF_3 at 10 PSI
1 pulse
1.1 J/cm^2

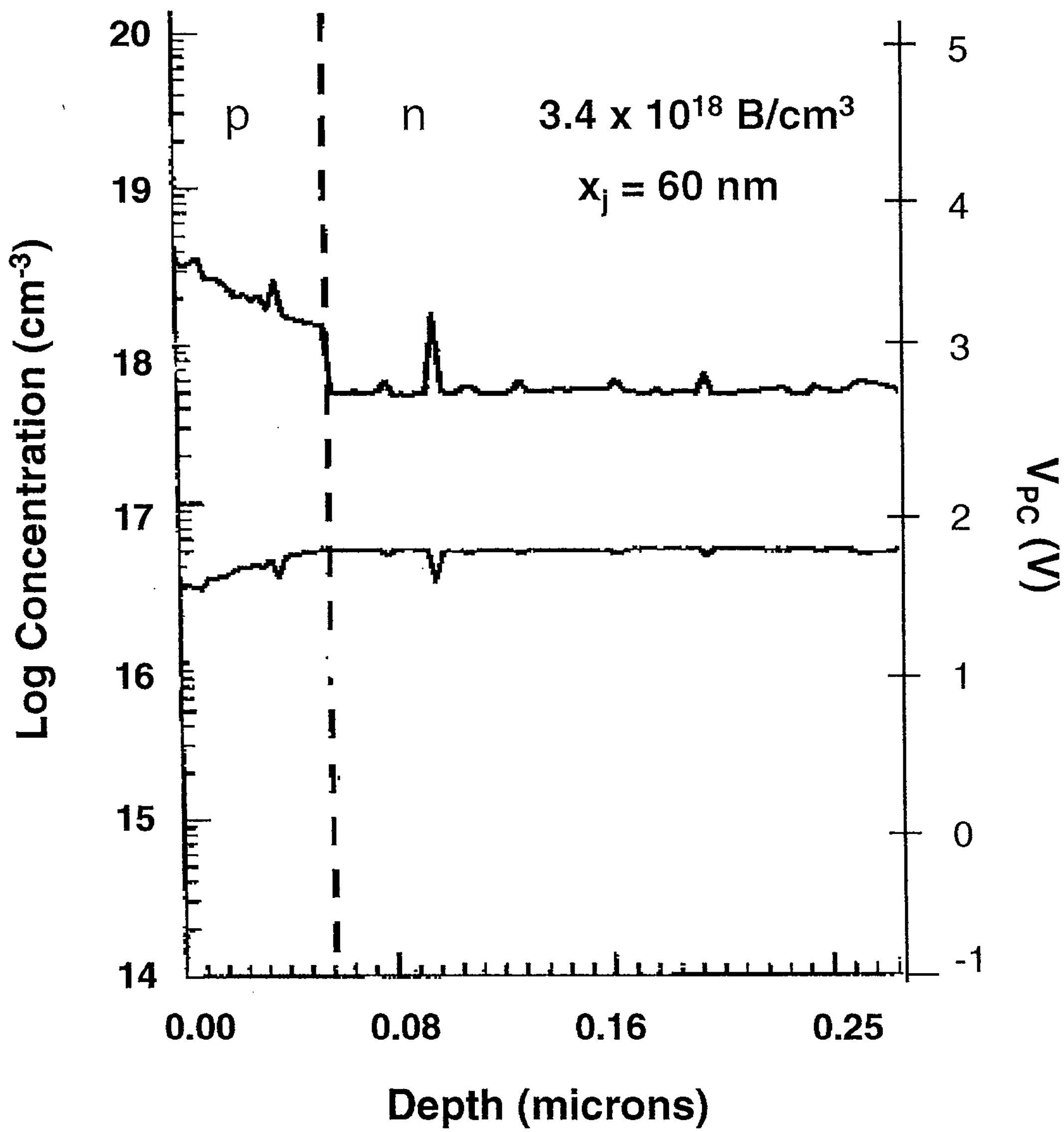


FIG. 9 PC-IV carrier concentration versus depth.

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(17) RBS measurements performed by Charles Evans & Associates, Redwood City, CA.
(18) PCIV measurements performed by Solid State Measurements, Inc., Pittsburgh, PA.

Conclusion

In-situ incorporation and activation of boron into SiC is demonstrated using excimer laser recrystallization in a boron trifluoride ambient. RBS and x-ray analysis demonstrate there is no crystalline damage during recrystallization at laser fluences below ~1.4 J/cm^2. Point-contact current voltage measurements confirm dopant activation, and the formation of shallow (~60 nm) pn-junctions in SiC. The abruptness of the junction edge is characteristic of a laser formed junction where enhanced diffusion occurs during the molten phase. This single pulse incorporation of dopants and simultaneous activation is the first demonstration of its kind in SiC, and has potential for forming low resistance contacts or shallow junctions in SiC devices.

Acknowledgments

This work was funded by the Office of Naval Research, Power Electronics Building Block (PEBB) Program under the auspices of Dr. George Campisi and Dr. Alan Tucker (ONR-334). Dr. Wayne McGinnis (SPAWARSYSCEN, Code D364) is thanked for his contributions to the x-ray analysis of the samples.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	April 1998	Final

4. TITLE AND SUBTITLE

IN-SITU LASER DOPING OF SILICON CARBIDE
Presentation at the March 1998 Meeting of the American Physical Society

5. FUNDING NUMBERS

PE: 0603508N
AN: DN306744
WU: EE49

6. AUTHOR(S)

S. D. Russell, A. D. Ramirez

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Space and Naval Warfare Systems Center
San Diego, CA 92152–5001

8. PERFORMING ORGANIZATION REPORT NUMBER

TD 3036

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Office of Naval Research
ONR 334
800 North Quincy Street
Arlington, VA 22217-5660

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

This Technical Document is a compilation of posters presented at the March 1998 meeting of the American Physical Society in Los Angeles, CA. It summarizes the inherent difficulties in fabricating silicon carbide microelectronic devices, the novel laser setup used to form electrical junctions in silicon carbide, detailed analyses of the laser-processed materials, and applications for this technique. This is the first reported demonstration of incorporation and activation of dopants into silicon carbide using excimer laser recrystalization in the presence of a doping ambient.

14. SUBJECT TERMS

Mission Area: Command, Control, and Communications
power devices
silicon carbide

15. NUMBER OF PAGES

48

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	SAME AS REPORT

21a. NAME OF RESPONSIBLE INDIVIDUAL	21b. TELEPHONE *(include Area Code)*	21c. OFFICE SYMBOL
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